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SIMULATED METEOROID IMPACT TESTING ON A COMPOSITE EXPANDABLE STRUCTURE FOR SPACECRAFT AIRLOCK APPLICATION

William H. Carden

ARO, Inc.

April 1969

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NOTICES

SIMULATED METEOROID IMPACT TESTING ON A COMPOSITE EXPANDABLE STRUCTURE FOR SPACECRAFT AIRLOCK APPLICATION

William H. Carden
ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Air Force Aero-Propulsion Laboratory (AFAPL) of the Research and Technology Division of the Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio (Mr. Adam Cormier, Program Monitor) under Program Element 62402F, Project 8170, Task 04.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of Arnold Engineering Development Center (AEDC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The tests were conducted from December 1 through 29, 1967, and from August 15 through 29, 1968, under ARO Project No. VS0847, and the manuscript was submitted for publication on December 11, 1968.

The author wishes to express appreciation to Mr. Adam Cormier of AFAPL and Messrs. Leo Jurich, Lou Manning, and Bob Scoville, of Goodyear Aerospace Corporation, Akron, Ohio, for their assistance during the test program.

This technical report has been reviewed and is approved.

Eugene C. Fletcher Lt Colonel, USAF AF Representative, VKF Directorate of Test	Roy R. Croy, Jr. Colonel, USAF Director of Test

ABSTRACT

Simulated meteoroid impact tests were conducted on an expandable, elastic recovery, four-layer composite material proposed for flight testing in a dummy airlock configuration aboard a NASA S-IVB Orbital Workshop. The tests were conducted to obtain the ballistic limit of the structure and to determine its behavior during simulated meteoroid perforation while enclosing a typical oxygen-rich spacecraft atmosphere. Spherical aluminum projectiles at a velocity of about 20, 000 ft/sec were used on the tests, and perforation occurred for projectile masses greater than about 0. 004 gm. The resistance of the structure to perforation was not affected by the presence of oxygen at 5 psia behind the test sample except under certain conditions in which the structure was compressed by the gas pressure together with the clamping arrangement used to fasten the sample to the test tank. The combustion front which exists inside a vessel containing a high concentration of oxygen when the vessel is perforated by a high-speed projectile was photographically recorded.

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SECTION I
INTRODUCTION

As spacecraft cabins become larger and crew size increases, it becomes impractical to require the decompression of the entire vehicle to permit egress or ingress maneuvers. Therefore, an airlock system will be utilized to eliminate the decompression and compression cycling of the complete spacecraft cabin.

The use of lightweight expandable materials in the construction of the airlock has been proposed to conserve weight and storage volume during launch. The airlock would remain in a stowed configuration until completion of the launch phase. The airlock could then be deployed to its operational expanded configuration, which would be maintained by inherent rigidity, chemical rigidization, or other mechanical means.

One material under consideration for use in an airlock is an expandable, elastic recovery, four-layer composite material fabricated by the Goodyear Aerospace Corporation (GAC). This material, in a dummy airlock configuration, is scheduled for flight testing on a NASA Apollo Applications Program (AAP) S-IVB Orbital Workshop. However, prior to flight testing, it was desired to provide laboratory simulation of meteoroid impact upon the composite structure.

This report presents the results of these simulated meteoroid impact tests. The tests were conducted to obtain the ballistic limit of the structure and to determine its behavior during simulated meteoroid perforation while enclosing a typical oxygen-rich spacecraft atmosphere. The tests were conducted in AEDC Impact Range S-2 (Armament Test Cell, Hyperballistic (S2)) of the von Kármán Gas Dynamics Facility (VKF).

SECTION II
APPARATUS

2.1 LAUNCHER AND RANGE

Range S-2 includes: (1) a two-stage launcher, (2) a blast tank into which muzzle gases expand and in which the projectile is separated from the sabot, (3) a connecting tube along which velocity measuring shadowgraphs are located, and (4) a target tank where the test specimen is impacted by the projectile. Figure 1, Appendix I, is a sketch of the complete range with identification of each of the major components. A complete description of the range, including instrumentation, is given in Ref. 1.

2.2 PROJECTILE AND SABOT

All projectiles used on these tests were basically type 2017 aluminum spheres, ranging in diameter from 1/32 to 1/8 in. In some cases it was desirable to launch a mass slightly less than that of a 1/16-in.-diam sphere. In these instances mass was removed from one side of the 1/16-in.-diam sphere until the desired projectile mass was obtained. Thus, these projectiles were not true spheres, since one side was flattened. However, this minor shape change was expected to be of no consequence in the test results.

The projectiles were adapted to the launcher by means of a four-piece, saw-toothed, Lexan® sabot. A rifled launch tube (1 turn in 10 ft) was used to separate the sabot quarters from the projectile by means of the spin-generated forces.

2.3 TEST MATERIAL DESCRIPTION

The expandable structure material under investigation was a four-layer composite of flexible materials, shown schematically in Fig. 2 and described by Goodyear (Ref. 2) as follows:

> Pressure Bladder - The pressure bladder is a laminate of three (3) individual sealant layers with an inner layer of 0.3-mil aluminum. The inner sealant layer is a laminate of nylon film-cloth. This layer is bonded with polyester adhesive to a second layer of closed-cell EPT foam 1/16 in. thick. The outer sealant is a nylon film-cloth laminate coated with a polyester resin. The total weight of the bladder composite is 0.159 psf and is independent of design pressure.
>
> Structural Layer - The filament winding manufacturing process is utilized for the structural layer and provides near the optimum in lightweight load carrying flexible structure. The structure layer will be wound utilizing a strand of three 0.0036-in. stainless steel wires interlaced with a rayon yarn in a winding pattern of 32 hoop filaments and 29 longitudinal filaments per inch.
>
> Micrometeoroid Barrier - Micrometeoroid protection is achieved by a 1-in. layer of flexible polyester foam. Flexible foam of 1.2 psf density has been selected as a suitable barrier material, based on hypervelocity particle impact tests. While the primary

function of the foam would be to act as a micrometeoroid barrier, it also serves as a deployment aid. During packaging, the foam layer would be compressed to about 10 percent of its original thickness and restrained by the packaging canister. Upon deployment in orbit, the canister would be released and the elastic recovery characteristics of the foam would help shape the airlock to its fully expanded volume.

Outer Cover Layer - The outermost layer of the composite wall structure encapsulates the wall to provide a smooth base for the application of a thermal coating. Inasmuch as the outer cover would encapsulate the composite wall, it would serve as an aid in packaging the structure prior to launch. By a vacuum technique, the wall thickness could be compressed from the fully expanded thickness to about 1/4-in., suitable for folding and subsequent packaging in the canister. A passive thermal control coating would be applied to maintain material temperature within acceptable limits.

2.4 TEST CONFIGURATIONS

The test program can be divided into two main phases as follows:

Phase I - Ballistic limit tests

Phase II - Tests in the presence of a spacecraft atmosphere

The test requirements for Phase I required no specific additional test hardware other than that required to support the target sample in a plane normal to the projectile line of flight. The target samples (12 in. square) were lightly supported on the edges and unsupported at the rear surface. The additional test hardware required for Phase II included a tank to contain the test atmosphere, a gas charging system for this tank, and a device for clamping the target sample onto the end of the tank.

A test tank 3 ft in diameter by 5 ft long was used on the first five shots in Phase II. This test tank was not available for the remaining shots in Phase II, which were conducted at a later date, so a smaller (2-ft-diam by 3.5-ft-long) tank was used in its place. The test atmosphere in the tank was oxygen at a pressure of 5 psia (≈260 torr). Charging of the test tank was accomplished after the tank was evacuated to a low pressure, typically about 1 torr. The range pressure (outside the test tank) was maintained at about 1 torr during each shot.

It was necessary for the target specimen to be attached to the up-range end of the test tank in a manner which would prevent gas leakage through the tank opening. It was determined that sealing could be obtained by clamping the test specimen to the tank wall if a small quantity of RTV 892 adhesive were used between the back of the specimen and the tank wall. Three different clamping arrangements were used in this phase of testing, as shown in Fig. 3. In each case, a clamping ring was used to provide a uniform pressure on the front of the specimen.

The first clamping arrangement (Fig. 3) was used with 12-in.-square target specimens. It should be recognized that the polyurethane foam directly under the clamping ring was greatly compressed, as shown in Fig. 4. The target area inside the clamping ring was also compressed slightly. Further, it can be observed in Fig. 3 that an overpressure of 5 psia behind the target specimen could result in additional compression of the target area inside the clamping ring, since the outer surface of the target specimen is somewhat restrained by the ring.

The second clamping arrangement (Fig. 3) was provided to eliminate compression of the polyurethane foam and stressing of the outer layer of the target specimen. The target specimen was modified by removing the outer layer and foam layer from all except the center area (6-in.-diam) of the target, as shown in Fig. 5. The clamping ring held only the structural layer and the pressure bladder. Thus, the polyurethane foam and the outer layer were essentially free of restraints.

The third clamping arrangement (Fig. 3) was used to provide verification of differences in the impact behavior observed with the first two clamping arrangements. A smaller clamping ring was used, so that compression was again applied to the foam layer.

SECTION III
TEST RESULTS

3.1 BALLISTIC LIMIT TESTS

The first phase of testing was conducted to determine the ballistic limit of the expandable structures material. These tests were conducted over a velocity range from 14,000 to 21,000 ft/sec. The presence or absence of target perforation was determined by visual inspection immediately following each shot. Examples of sectioned targets showing impact damage are presented in Fig. 6. For tests at conditions very close to the ballistic limit, it was possible to identify a test result denoted as "incipient" perforation. This description was used for those

tests for which it was evident that target perforation almost occurred or just barely occurred, as evidenced by a softening of the rear surface of the target or a minute pinhole through the rear surface.

These results are tabulated in Table I, Appendix II, and plotted in Fig. 7. It appears that perforation of the test specimen can be expected at the velocities tested if the mass of the aluminum sphere is greater than approximately 0.004 gm. The range of velocities was not large enough to identify a velocity effect on the ballistic limit in the present tests.

3.2 SPACECRAFT ATMOSPHERE TESTS

The second phase of testing was conducted with the specimen attached to the tank. Tests were conducted with oxygen at 5 psia inside the tank, behind the test specimen. Other tests were conducted without gas pressure in the tank. The results of all Phase II tests are tabulated in Table II and plotted in Fig. 8.

The test results for those shots using clamping arrangement No. 1 with oxygen inside the test tank (Fig. 8) indicated an apparent decrease in the ballistic limit of the target specimen, when compared with the ballistic limit results for Phase I (Fig. 7). On the basis of the one shot (No. 59) which was conducted with a vacuum in the test tank and which did not result in perforation, this ballistic limit decrease was attributed to the presence of the gas inside the test tank.

At this point in the test program, the original supply of target specimens furnished by GAC had been expended. However, the mechanism by which the presence of gas inside the test tank affected the ballistic limit remained to be determined. An additional supply of target specimens, in the configuration shown in Fig. 5, was furnished by GAC for use in further testing to identify this mechanism.

Clamping arrangement No. 2 (unrestrained front surface) was used for tests conducted with oxygen at 5 psia inside the test tank, as well as for other tests conducted with a vacuum in the test tank. The test results (Fig. 8) for both tank conditions indicate a ballistic limit in agreement with that obtained for the Phase I tests (Fig. 7). These results demonstrate that the presence of oxygen behind the target specimen has no direct effect on the damage mechanism of the test material during impact. Furthermore, these results suggest that the decreased resistance to perforation obtained with the first clamping arrangement was

only an indirect result of the presence of gas inside the tank, whereby the gas pressure was able to significantly compress the foam layer of the target specimen.

In order to demonstrate conclusively the effect of foam layer compression on target perforation, four shots were made using clamping arrangement No. 3 (Fig. 3). Because of the additional constraint provided by the smaller openings in the clamping plate and tank wall, the mechanical compression of the foam layer near the vicinity of impact was much greater for this arrangement than for clamping arrangement No. 1. Therefore, while the gas pressure could provide a significant additional amount of compression in the first arrangement, it provided little additional compression in the third arrangement. Target perforation occurred on all four of these shots (Fig. 8), two of which were made with a vacuum in the test tank, even though the projectile mass was far below the ballistic limit previously obtained for uncompressed targets.

The results of these three groups of tests in Phase II, when examined together, indicate that the resistance of the target material to perforation by a simulated meteoroid is not decreased by the presence of a typical spacecraft atmosphere behind the test sample. The anomolous results obtained with the first target clamping arrangement can be safely attributed to the compression of the foam layer by the gas pressure inside the tank when such a clamping arrangement is used.

3.3 IMPACT-INITIATED COMBUSTION FRONT

The perforation of the wall of a vessel by a hypervelocity projectile will produce an explosive-like reaction inside the tank if the tank contains an oxygen-rich atmosphere. Studies (Refs. 3 through 10) have shown that the extremely hot fragments of projectile and wall materials rapidly undergo a chemical reaction with the oxygen in the immediate vicinity of the perforation, producing a combustion front which penetrates into the tank. This violent reaction is accompanied by a brilliant flash of light and an intense level of sound. The combustion front and accompanying hot particles are potential ignition sources for other combustible material inside the tank.

Recent studies conducted for NASA (Ref. 11) have shown that the presence of a low-density, highly combustible material such as polyurethane foam as an integral part of the vessel wall can increase the duration and severity of the reaction beyond that obtained for a metallic wall. Secondly, and perhaps more seriously, the foam material which

surrounds the point of impact can ignite as a result of the impact, causing a fire to spread and burn along the tank wall. Since the expandable structure material under study contains a large volume of polyurethane foam, and since the material will enclose an oxygen-rich atmosphere in its space applications, provisions were made on these tests for photographic observation of the reaction inside the test tank when perforation occurred with oxygen inside the tank.

Camera coverage on the first group of Phase II shots (those utilizing clamping arrangement No. 1) was obtained through a side port in the test tank immediately behind the upstream tank flange, so that the uprange edge of the field of view was about 6 in. behind the rear of the test sample. Camera coverage on the remaining shots was obtained through a rear port in the test tank, looking directly at the inside surface of the test sample. A 16-mm Fastax® camera was used, and the framing rate during the event ranged from 3600 to 4500 frames per second. Typical photographic results are presented in Fig. 9. All luminosity inside the test tank resulted from the phenomena associated with perforation of the expandable structure material in the presence of oxygen.

The first three film clips in Fig. 9 were recorded through the side port for impact of projectiles of three different sizes at the same nominal velocity, about 20, 000 ft/sec. The volume and relative intensity of the events recorded on the film increase with increasing projectile mass. The complete durations of the events on these tests, of which only the initial portions are shown in the film clips, were typically between 10 and 20 msec. The third film clip represents an order of magnitude increase in projectile mass over that for the first two film clips. The field of view in the third film clip, which was limited by port size, was about 11 in. The streaks which appear in the first frame of the third film clip probably result from high velocity metallic particles from the projectile and test specimen. The billowing clouds which follow are typical of the results when a low-density material such as polyurethane foam is present in the wall structure.

The fourth film clip in Fig. 9 is typical of those recorded through the rear port of the test tank. Impact conditions were similar to those which produced the first two film clips. The image size on the fourth film clip is small because the distance from the event to the camera was about twice as great as that for the side-view configuration.

The hazards associated with meteoroid perforation into an oxygen-rich environment can be separated into two groups; specifically, those hazards which could incapacitate an occupant (light flash, sound intensity level, overpressure), and those which produce damage to the spacecraft

itself. This latter group includes loss of pressurization, impact damage of spacecraft components, ignition and burning of wall insulation materials, and secondary fires initiated by hot fragments. Little is known about the "shock" hazards to an astronaut, and the present tests were not extensive enough to provide clarification in this area. Neither were these tests sufficient to provide a wealth of information concerning potential damage to an expandable structures vehicle. However, it may be significant that ignition and burning of the test specimen materials did not occur on any of the tests conducted in the presence of oxygen. This does not imply that ignition and burning of the polyurethane foam would not occur under other impact conditions; in Ref. 11 it was found that ignition and burning could be expected when the projectile kinetic energy was greater than a certain threshold value. The projectile energy in the present tests was apparently somewhat below the threshold value applicable in the present case, if, in fact, such a threshold exists for the structure studied.

SECTION IV
SUMMARY

The impact tests conducted on samples of the expandable structures material indicate that complete perforation of the test specimen can be expected at the velocities tested if the mass of the aluminum projectile is greater than approximately 0.004 gm. The resistance of the structure to perforation is not affected by the presence of oxygen at 5 psia behind the test sample. Certain anomolous results obtained in the presence of 5 psia oxygen are attributed to the compression of the foam layer of the structure by the gas pressure. The combustion front which exists when a vessel containing a high concentration of oxygen is perforated by a high-speed projectile was photographically recorded. A greater understanding of the hazards associated with this impact-initiated combustion front will require additional testing.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES

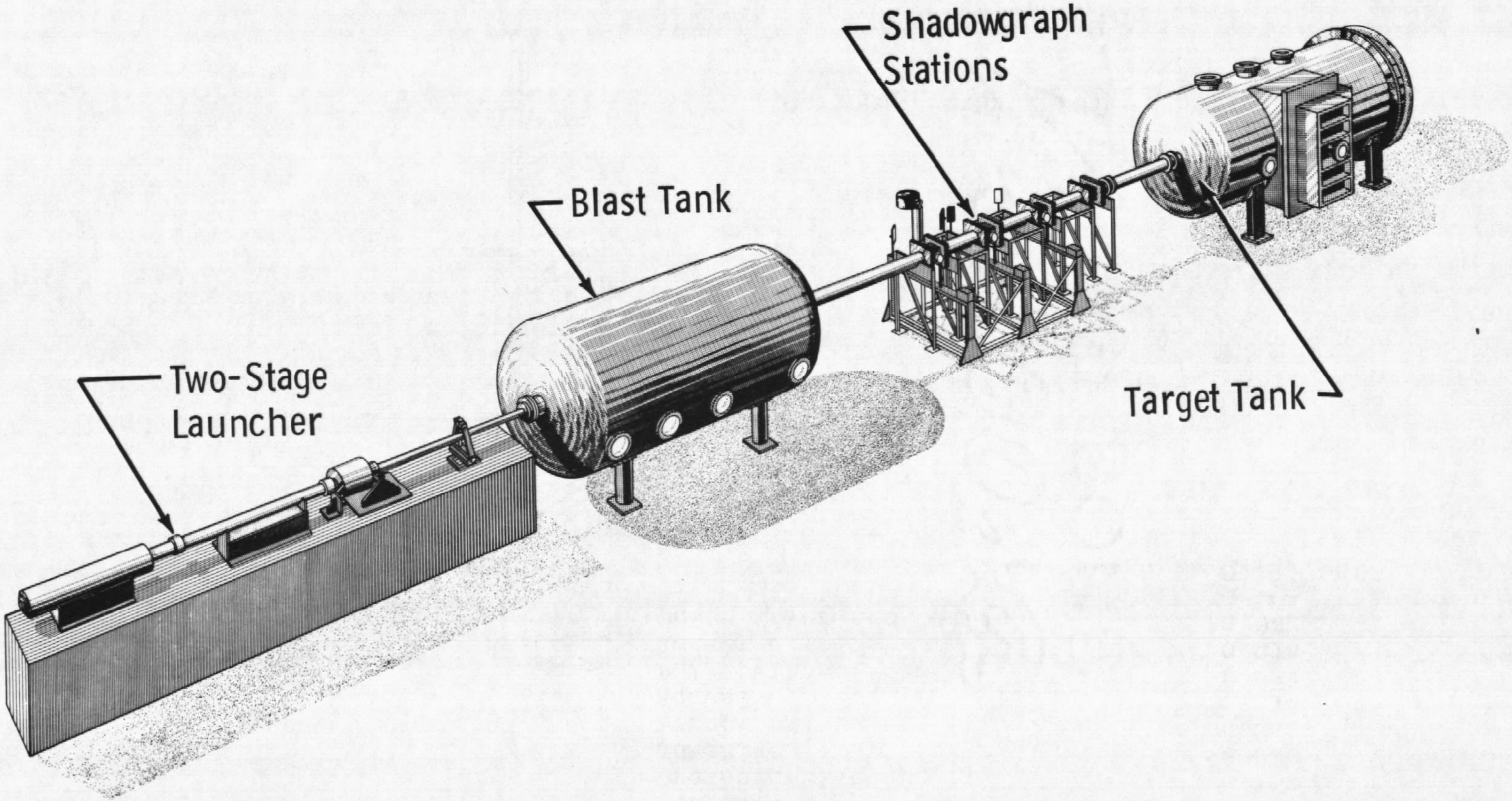

Fig. 1 S-2 Hypervelocity Impact Range

CONSTRUCTION AND WEIGHT

Aluminum Inner Layer	0.004
Adhesive	0.010
Pressure Bladder	0.159
Adhesive	0.010
Structural Layer	0.062
Adhesive	0.010
Polyurethane Foam	0.084
Adhesive	0.010
Outer Cover and Coating	0.062
Total Weight	0.411 psf

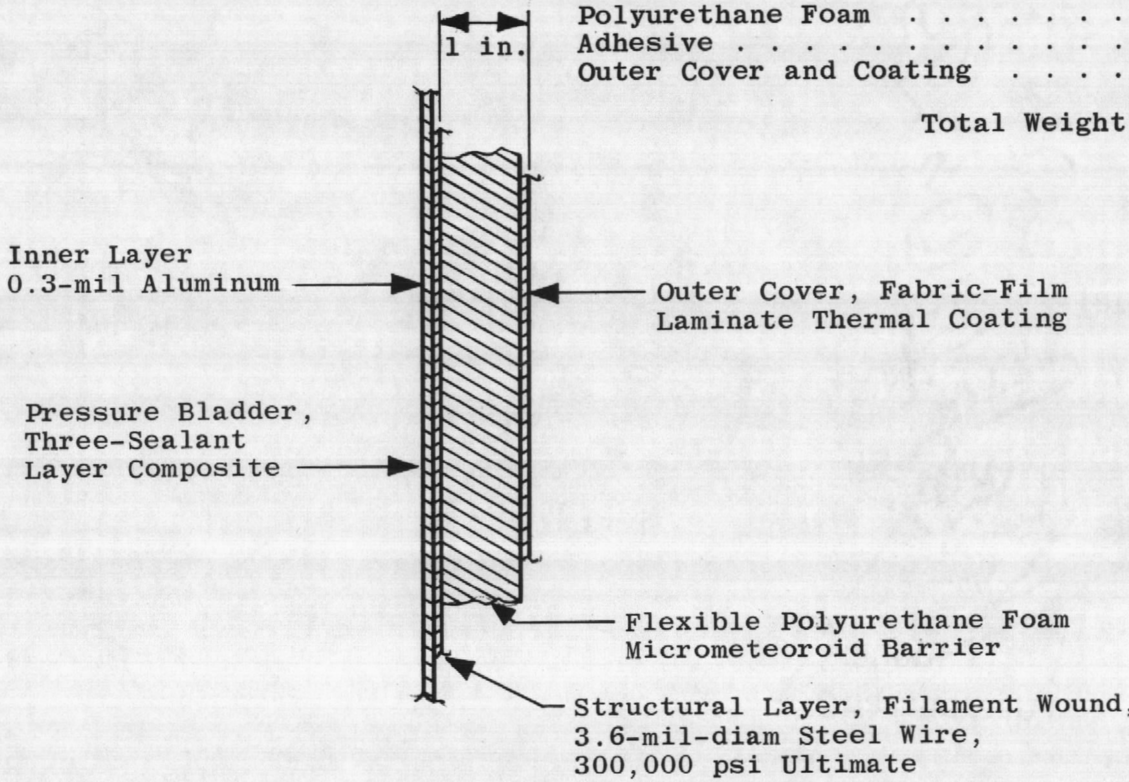

Fig. 2 Description of Expandable Structure Material

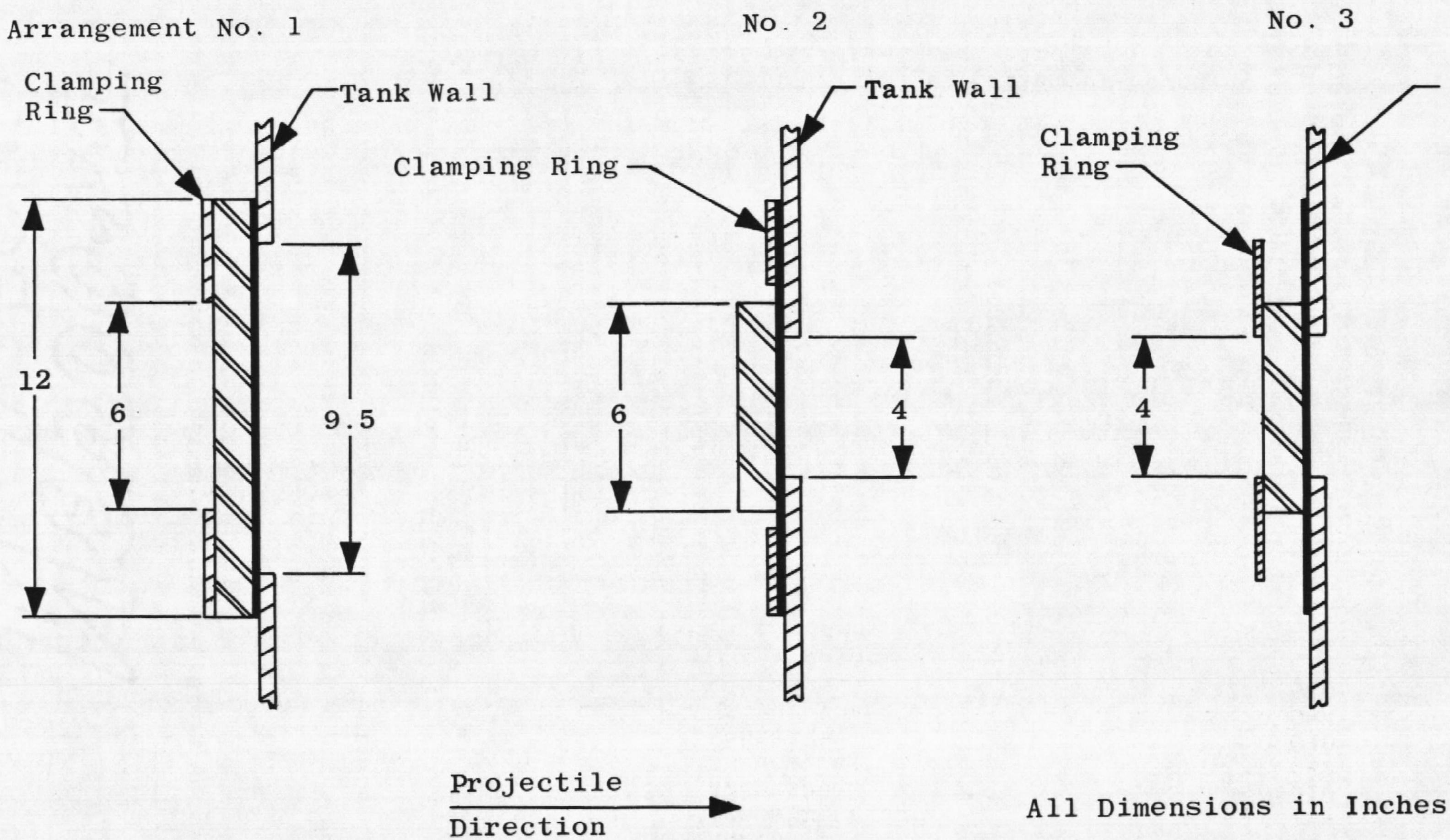

Fig. 3 Target Clamping Arrangements

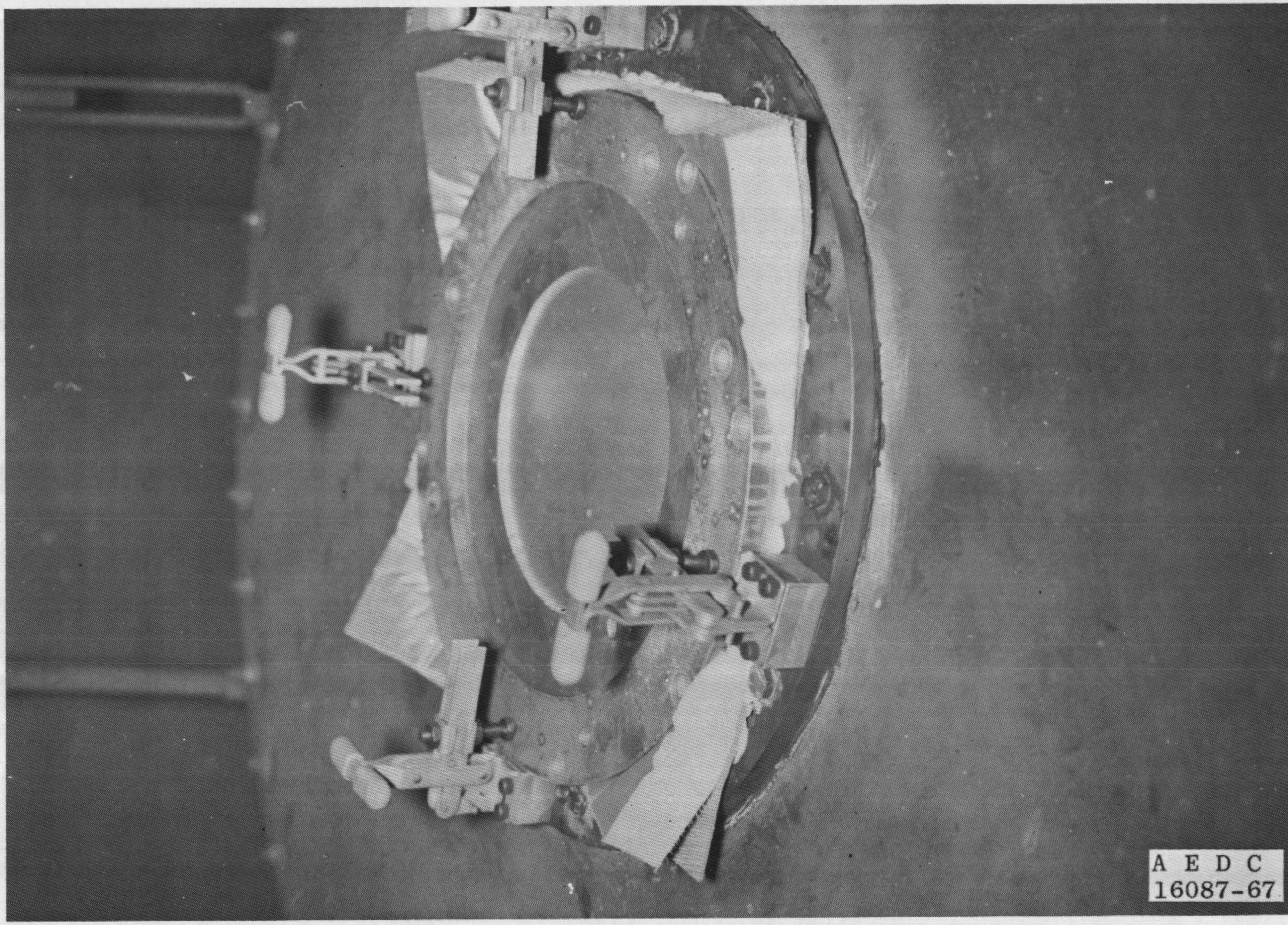

Fig. 4 Target (12-in.-Square) with Clamping Arrangement No. 1

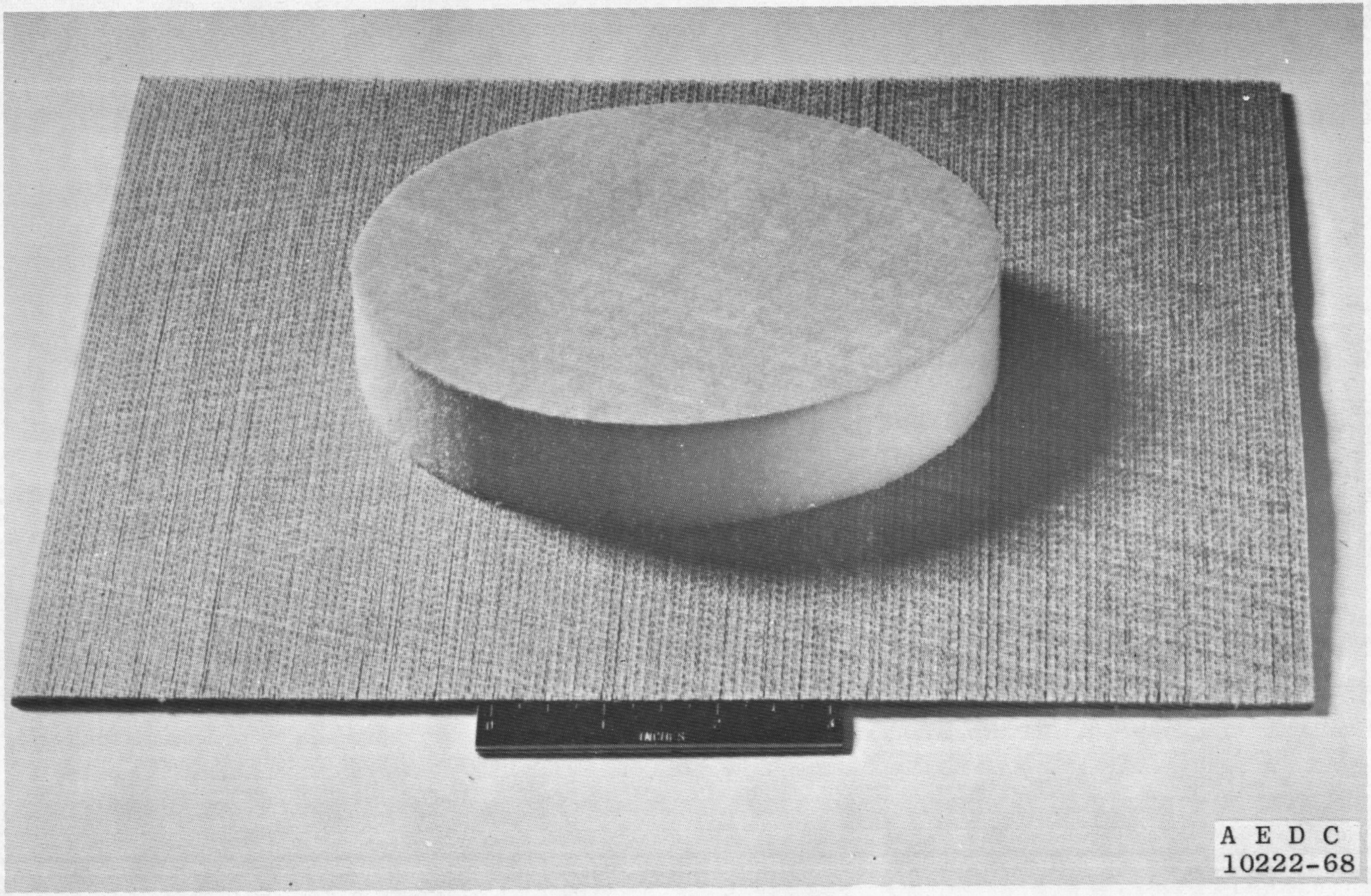

Fig. 5 Modified Target Specimen

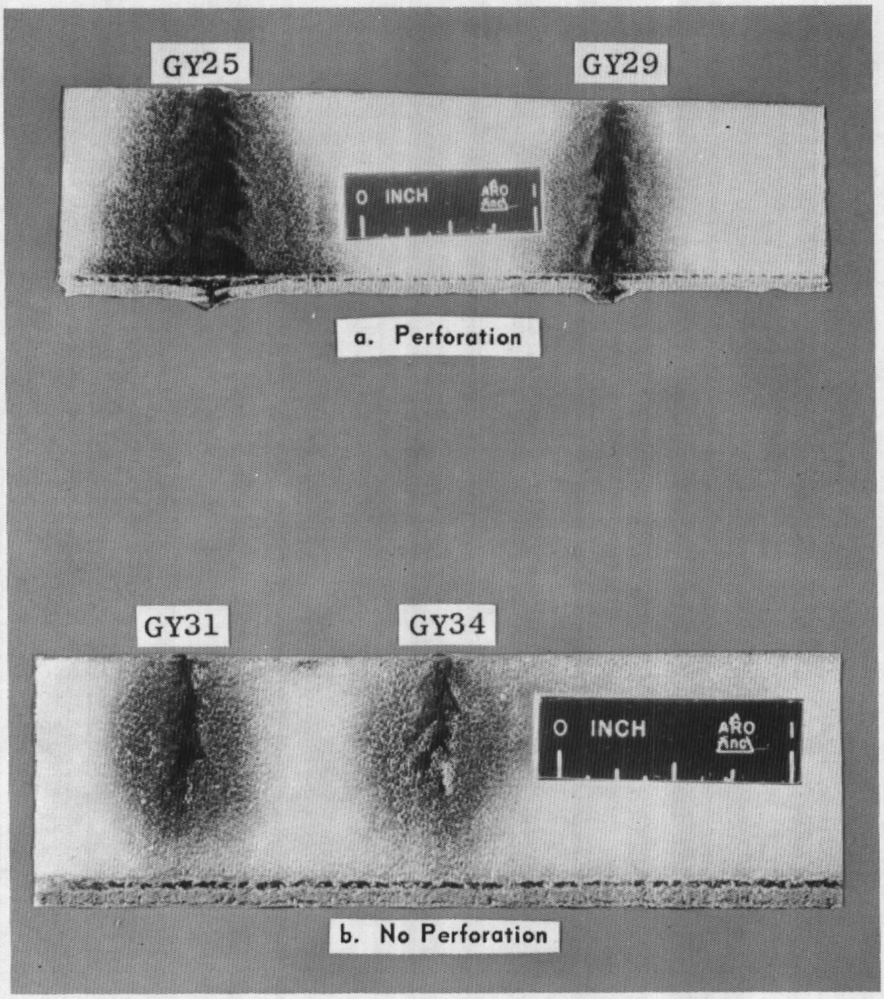

Fig. 6 Section View of Target Damage

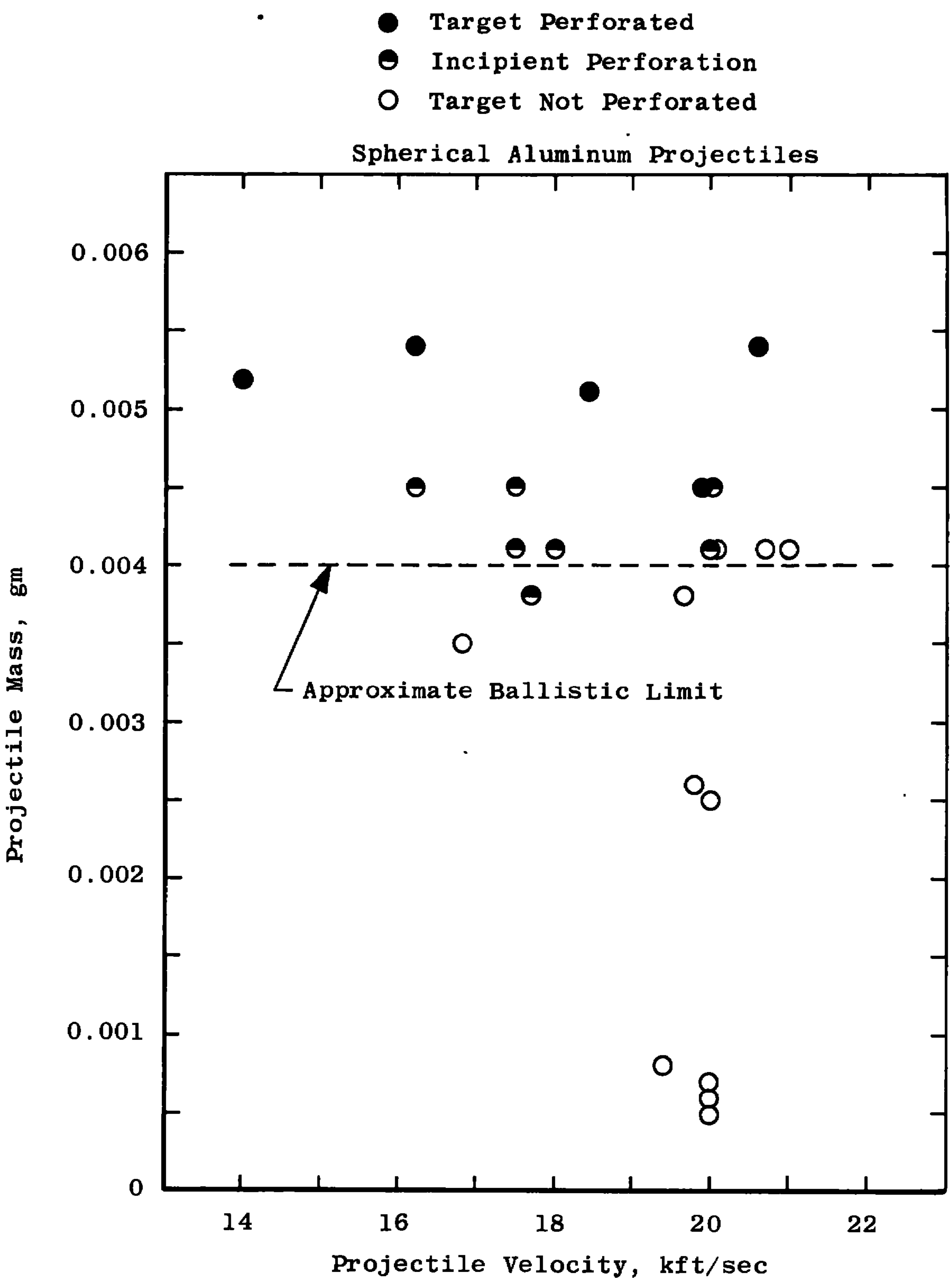

Fig. 7 Ballistic Limit Test Results

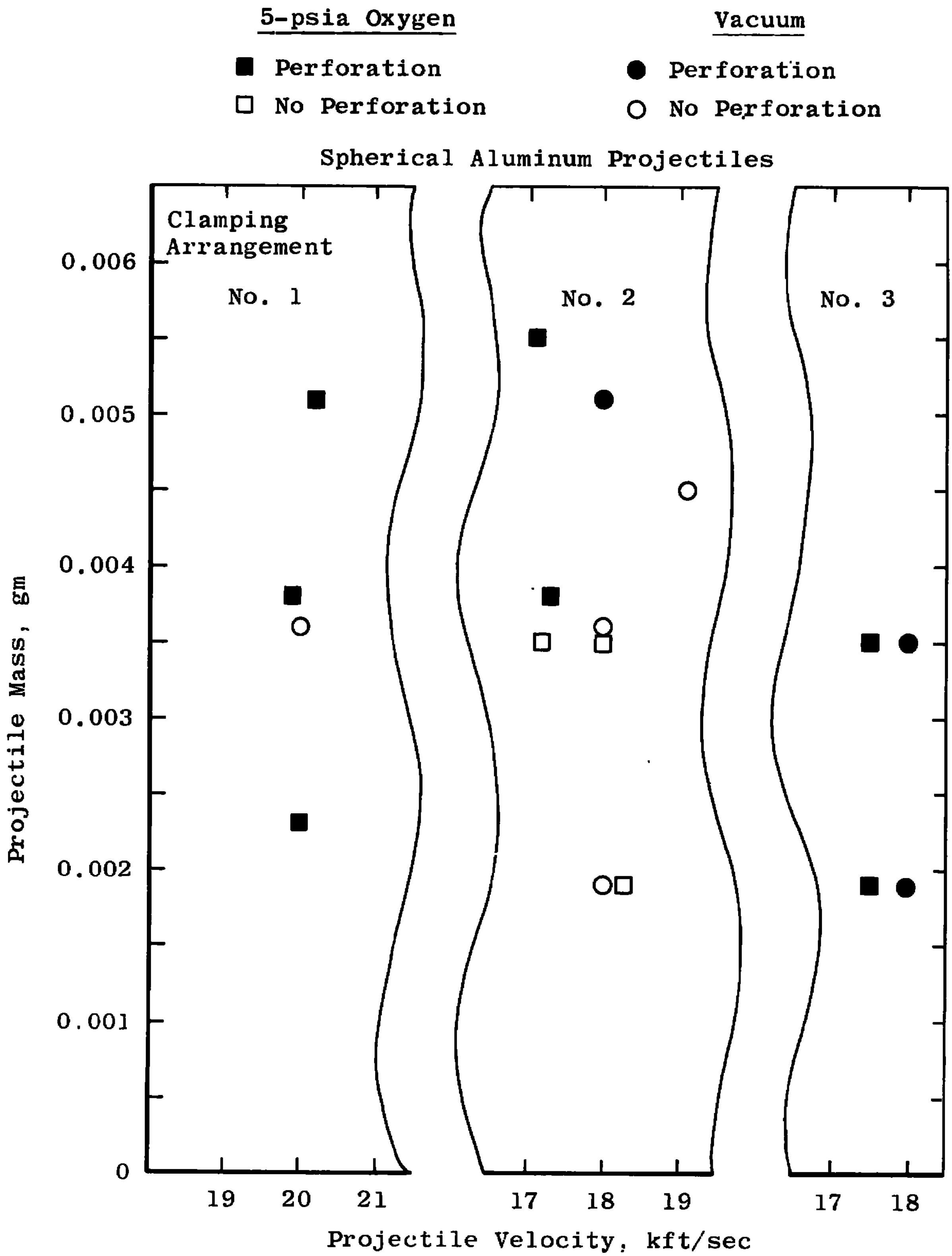

Fig. 8 Spacecraft Atmosphere Test Results

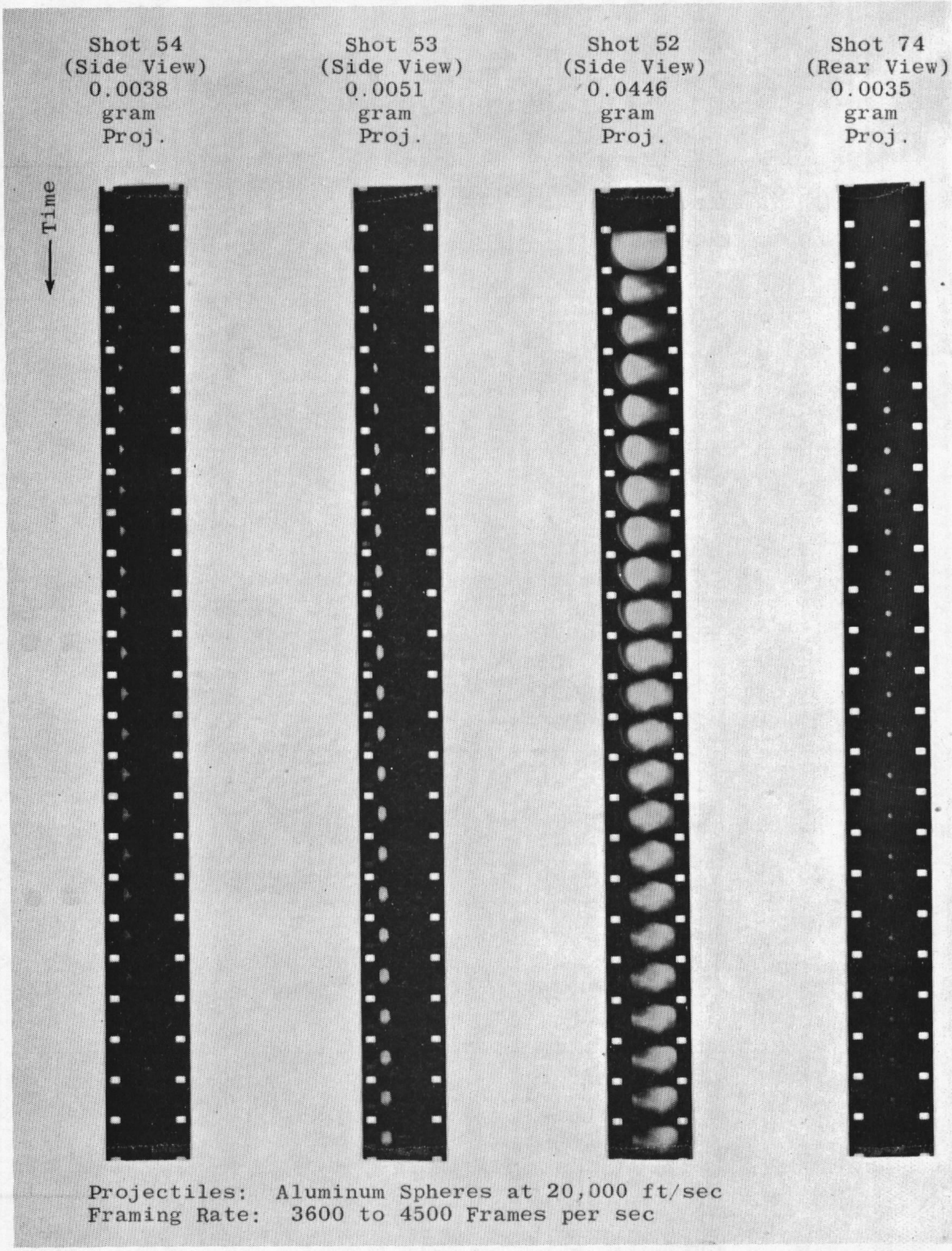

Fig. 9 Impact-Initiated Combustion Front

TABLE I
BALLISTIC LIMIT TEST RESULTS

Shot No.	Aluminum Projectile			Target Perforation		
	Diameter, in.	Mass, gm	Velocity, ft/sec	Yes	Incipient	No
25	1/16	0.0054	20,600	x		
26		0.0051	18,450	x		
27		0.0054	16,200	x		
29		0.0052	14,000	x		
31	1/32	0.0005	20,000			x
32		0.0007	20,000			x
33		0.0006	20,000			x
34		0.0008	19,400			x
35	3/64	0.0026	19,800			x
36		0.0025	20,000			x
37	1/16 Mod.*	0.0041	20,000		x	
38		0.0045	19,900	x		
39		0.0038	20,100			x
40		0.0041	17,500		x	
42		0.0045	16,200		x	
43		0.0045	17,500		x	
44		0.0041	18,000		x	
45		0.0036	19,650			x
46		0.0038	17,700		x	
47		0.0041	20,700			x
48		0.0041	21,000			x
49		0.0045	20,000		x	
50		0.0035	16,800			x

*Mass Removed from One Side of Sphere

TABLE II
SPACECRAFT ATMOSPHERE TEST RESULTS

Shot No.	Aluminum Projectile			Gas	Clamping Arrangement	Target Perforation	
	Diameter, in.	Mass, gm	Velocity, ft/sec			Yes	No
52	1/8	0.0446	20,600	5 psia O_2	No. 1	x	
53	1/16	0.0051	20,200			x	
54	1/16 Mod.*	0.0038	19,900			x	
58	3/64	0.0023	20,000			x	
59	1/16 Mod.	0.0036	20,000	Vacuum			x
62	1/16	0.0055	17,100	5 psia O_2	No. 2	x	
65	1/16 Mod.	0.0035	17,200				x
67		0.0038	17,300			x	
68		0.0035	18,000				x
69		0.0036	18,000	Vacuum			x
70		0.0045	19,100				x
71	1/16	0.0051	18,000			x	
73	1/16 Mod.	0.0035	18,000		No. 3	x	
74		0.0035	17,500	5 psia O_2		x	
76	3/64	0.0019	18,000	Vacuum		x	
77		0.0019	17,500	5 psia O_2		x	
78		0.0019	18,300		No. 2		x
79		0.0019	18,000	Vacuum			x

*Mass Removed from One Side of Sphere

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13. ABSTRACT

Simulated meteoroid impact tests were conducted on an expandable, elastic recovery, four-layer composite material proposed for flight testing in a dummy airlock configuration aboard a NASA S-IVB Orbital Workshop. The tests were conducted to obtain the ballistic limit of the structure and to determine its behavior during simulated meteoroid perforation while enclosing a typical oxygen-rich spacecraft atmosphere. Spherical aluminum projectiles at a velocity of about 20,000 ft/sec were used on the tests, and perforation occurred for projectile masses greater than about 0.004 gm. The resistance of the structure to perforation was not affected by the presence of oxygen at 5 psia behind the test sample except under certain conditions in which the structure was compressed by the gas pressure together with the clamping arrangement used to fasten the sample to the test tank. The combustion front which exists inside a vessel containing a high concentration of oxygen when the vessel is perforated by a high-speed projectile was photographically recorded.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
meteoroids						
impact tests						
passageways						
structures, expandable						
artificial satellites						
manned spacecraft						
space stations						
parking orbits						
hypervelocity projectiles						
combustion						
fire hazards						
noise (sound)						
light (visible radiation)						
brightness						

AFSC
Arnold AFS Tenn

UNCLASSIFIED

Security Classification